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Marsden Manson

Volume I
(1907)

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An Attempt to Explain the Evidences of Glacial Action During the Permian

in pp 12-13

by

Marsden Manson, C. E., Ph. D.
Member and Delegate of
the California Academy of Sciences
Mem. Am. Soc. C. E.
F. R. G. S.
Mem. Technical Society of the Pacific Coast, etc.

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An Attempt to Explain the Evidences of Glacial Action During the Permian

WIDE-SPREAD EVIDENCES OF ICE AS A GEOLOGIC AGENT.

During many, if not all, of the great divisions of geologic time ice formed over considerable areas, acted gravitatively, and left legible evidences of its work as a geologic agent of magnitude.*

The period of greatest extent was during pleistocene time.|| This has been called "The Great Ice Age," and the general acceptance of this term is evidence of the view held by geologists that there have been other but lesser ice ages.

The acceptance of this view has been so universal that the mere finding of evidence of the gravitative action of ice, at any latitude and at any geologic horizon, is quite readily accepted as proof of a glacial epoch or period.† To account for these evidences a number of hypotheses have been advanced, but none of these has proved generally acceptable.‡ This is not surprising when we consider the inchoate stage which this fascinating branch of the all-absorbing science of geology has reached. Geologists yet living have seen the almost incredible hypothesis, that ice in continental sheets has but recently overspread temperate latitudes, established as a truth by a mass of incontrovertible evidence. Within a generation these facts have been massed into a new branch of geology to which ardent specialists have devoted their life's work. Without pausing to agree upon the prime cause of the remarkable climatic changes indicated by these phenomena, this age has been subdivided, and apparent variations in the character and time of the deposits or of the direction

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4th ed. Vol II p 1001 et seq.

* Sir A. Geikie. Text Book of Geology, ~~3rd ed.~~, ~~p. 23.~~

2. Chamberlin and Salisbury, 272—3.

|| 3. Chamberlin & Salisbury, p. 327.

† *Shaler and Davis,* Glaciers, p. 70.

‡ *Prof. J. Geike.* The Great Ice Age, 3rd ed., p. 381.

Le Conte. Elements of Geol., ed. 1901, p. 381.

Bonney. Ice Work Present and Past. p. 260.

Suess. The Face of the Earth, Vol. II, pp. 252, 253. (Sollas' Translation, Oxford, 1904.)

and limits of flow, have been classified in stages and separated into glacial and interglacial periods, etc.*

Glacial phenomena recognized to have but recently passed from middle latitudes in both hemispheres and yet passing before our eyes at sea level in both Antartic and Arctic latitudes† were and are upon so stupendous a scale that many scientists accept evidence of the gravitative action of ice as sufficient proof of an ice age or glacial period during any era of geologic time, and let analogy and the imagination supply any deficiency in the extent and continuity of this evidence and without being too circumspect as to a lack of corroborative evidence of contemporary life of boreal habit.||

PHENOMENA OF GLACIATION DURING THE PERMIAN.

Next in extent after the glacial deposits of the Ice Age stand those laid down during Permian time; which, by reason of their remarkable distribution about the tropics and the synchronous presence of warm-temperate and tropical life in the same and all other latitudes, have attracted wide attention and incited frequent attempts to explain them. The lack of evidence of contemporaneous life of arctic habit, and of cold-temperate forms during either preceding or succeeding epochs also constitutes a marked and significant feature, which should caution the student against too broad an interpretation of the evidences of ice action in Permian formations.‡

So exacting are the conditions which these apparently irreconcilable phenomena impose that they are cited by Chamberlin as the climacteric problem of geologic time.§ These exacting conditions have such broad

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* De Lapparent appears to doubt the wisdom of this subdivision. Traité de Géologie, p. 1642.

† Journal of Geography, Vol. XXVI, July 1905. pp. 23 and 27.
Journal of Geography, Vol. XXV, April 1905. pp. 364-5.
Am. Geologist, Vol. XIX, No. 4, p. 263, et seq.

|| 2. Chamberlin & Salisbury, 637.

‡ Life was frequently dwarfed in middle latitudes during the Permian, whilst in the same and higher latitudes such dwarfing does not appear to have taken place. indicating local causes favorable or unfavorable to life. See also 2. Chamberlin and Salisbury, 656.

§ *Science,* Vol. XXIV, p. 532. The present writer is not now in accord with this view and holds that evidences of Permian glaciations, like all other evidences of glacial action preceding the Ice Age, are of similar character and cause, varying only in location and extent; and, that the Ice Age marks the climacteric period of the entire geologic history.

bearings upon the great problems of geologic, present and future climates, that they cannot be entirely separated from the general problem. The discussion will therefore be general and later will be specifically applied to the special problem presented by Permian glaciations.

Notable for breadth and thoroughness among these attempts to explain Permian glaciation stands that of Prof. Wm. M. Davis,* who visited the Dwyka formations of South Africa during the excursions of the British Association for the Advancement of Science, in 1905. Prof. Davis, who is eminently qualified for the task, essays the explanation of these evidences of ice action along the lines of each of the following factors, which underlie the several hypotheses which have been advanced from time to time by various authorities to account for evidences of glacial action.

Prof. Davis says:

"The climatic conditions under which the Dwyka ice sheet was formed offer a most interesting subject for inquiry. The chief factors to be considered in this connection are (A) 1, altitude of the Dwyka land surface above the sea level of its time; 2, distance from the continental margin, as the continent was then shaped; 3, form of the Dwyka area and its relation to neighboring mountains and highlands of Permian time; (B) various atmospheric factors, such as composition, temperature and circulation; (C) certain astronomical factors; (D) and the latitude of the glaciated area, as latitude was then arranged." †

It will be noted that Prof. D. places first in this arrangement of possible causes the three found under (A), which relate to changes in the elevation of the land surface. Taken in connection with the following quotation it would seem that he regarded this cause as the most probable one.

"Uplifted areas there must have been, however, somewhere in South Africa then or soon afterward, in order to provide the great bodies of sediment deposited in the heavy Karroo series." (p. 415 of work cited)

After a discussion of all the factors he reaches the conclusion: "The cause of the Dwyka glaciation for the present remains a puzzle, although the fact of glaciation is well established." (p. 420 of work cited)

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* Bulletin Geol. Soc. Am., Vol. 17, pp. 377-450.

† Bulletin Geol. Soc. Am., Vol. 17, Aug., 1906. p. 414.

Headings and subheadings lettered and numbered by the present writer for convenience of reference.

Prof. Davis thus reaches the conclusion that none of the factors or causes is adequate. The present writer concurs in this conclusion, having reached it, however, some years prior to the visit to the locality by the British Association and on different lines of investigation and comparison. * Since these hypotheses embrace the principal and most recent attempts to find or assign an adequate cause or causes for these and other glacial phenomena, the conclusion that none of them offers an adequate explanation leaves the subject open for study and discussion on the broadest lines; and, since Permian glaciation is an inseparable element in the general problem, the whole subject must be considered as a unit.

It is first essential to briefly recall the facts for which an explanation or cause is sought.

In India, South Africa, Australia and South America evidences of glacial action of marked extent occur in Permian formations. These are in regions adjacent to the tropics and extend in some instances into the torrid zone. It will be noted: (1) that these glaciations were developed in, or extended to, latitudes over which a vertical or nearly vertical sun shone for a considerable portion of each year.† (2) That during this period polar latitudes supported warm-temperate or tropical life.§ (3) That at sea level in all latitudes substantially similar or uniform life prevailed, although glaciers may have reached nearly or quite this level.|| (4) That there is an entire lack of evidence of the existence of life of boreal or arctic habit during either the Permian or the immediately preceding or succeeding periods.

PRIMARY THESES ESTABLISHED BY RECOGNIZED GEOLOGICAL PRINCIPLES.

These phenomena establish the thesis that the climates of Permian time were not, as at present, zonally distributed. The present knowledge of the physics of the atmosphere and of the action of solar energy establishes a second thesis: namely, that solar energy alone does not

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* Geological and Solar Climates, 1893.

The Evolution of Climates, 1903.

|| See 2. Chamberlin and Salisbury, p. 653.

† The author holds, with Geike and others that there is no evidence that the poles have been anywhere else than where they now are during geologic time. See also authorities referred to on p. 8.

§ 2. Chamberlin and Salisbury, 658-9.

establish and maintain a non-zonal distribution of temperatures on a planetary surface conditioned as is that of the earth.

However contradictory these theses may be of present conceptions of geologic climates, and however radically they may be opposed to present views and assumptions as to the cause of these climates, the prime questions are: Are *they true?* Do they lead to a reasonable explanation of phenomena which are admitted to have occurred and which are as yet without satisfactory explanations? And, do they tend to lead us out of the confusions and contradictions in which the subject is now involved? The acceptance of these theses as premises in the discussions may even necessitate the rejection of generally accepted, but as yet, unproved, assumptions as to the control by solar energy of the climates of the geologic eras preceding the present. These theses may not therefore pass unchallenged. They oppose accepted tenets of geological physics: it is consequently essential that their foundations be rigidly investigated, for upon them must rest not only an attempted solution of one of the most perplexing problems of climatology, but an attack upon time-honored tenets as old as the science of geology itself: for upon the unproved assumption, that solar energy was the controlling source of heat, rest all the attempts to account for or to explain the phenomena of geologic climates.

The first of these theses namely; that the climates of Permian time were not, as at present, zonally distributed, is likewise true of those of all other geologic eras except the present. It is only necessary to recall the distribution of fossil life, and particularly marine life, and of glaciation to establish the truth of this thesis, these phenomena having been distributed without regard to latitude. The very evidences of glaciation which we are considering were in part under a vertical sun and adjacent to and on either side of the tropics, whilst warm-temperate and tropical life flourished within the polar circles. Such distributions of glaciation and of life forbid the consideration of solar energy as the dominant and controlling source of heat. So strong is this evidence against a zonal distribution of climates that to explain tropical glaciation in Permian time, eminent scientists have been reduced to the necessity of considering a displacement of the poles of about 90 degrees; thus disrupting the gyroscopic stability of a spheroid having a diameter of nearly 8,000 miles and an equatorial bulge of 26 miles, having a tangential velocity of 1036.4 miles per hour. All the evidence available goes to prove that the poles have not materially shifted from their present positions in geologic time.* To establish the truth of this thesis it is only necessary to refer to the standard manuals of geology, yet the attempt has been persistently made to fit these adverse facts to the assumption that solar energy controlled the uniform sea-level climates which fossil life proves to have prevailed during all eras except the present.

We are therefore confronted with evidence, which is as yet uncontroverted, (1) that prior to the present era the surface temperatures of the earth were not distributed in zones: (2) it is not in accord with the present knowledge of the physics of the atmosphere and of the action of solar energy that this energy can develop and maintain planetary climates otherwise than zonally. It follows therefore, that any other distribution of surface temperatures than zonal must have been the result of the influences of conditions which extended to the period when the change took place from the non-zonal climates of geologic time to the zonal climates of the present era.

The progressive, although irregular retreat of glaciers and the corresponding advance of life, establish the subsidiary thesis, that the modifications of the conditions which existed at the inauguration of the present source of control have not yet reached their ultimate stage.

When one broadly interprets the record of life upon the earth it is manifest that it presents two marked and significant features: (1) The earliest life was of ultra-torrid habit, followed through successive ages by forms fitted for lower and lower temperatures until boreal and arctic forms were developed during a comparatively recent period, when glacial conditions reached a maximum: (2) The scale of temperatures, as established by fossil life, is the same in all latitudes up to the culmination of the Ice Age; since which period only have distinctively climatic zones of life and temperatures been established.

In this it is notable (1), that the Ice Age followed a period during which cold-temperate forms of life were quite uniformly distributed at all latitudes; that this life succeeded an equally wide distribution of forms of slightly warmer habit.† (2) That the ameliorating conditions succeeding the culmination of the Ice Age favored the development of life in zones and that these ameliorating conditions are yet being extended poleward and to greater altitudes in all latitudes.

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* Sir A. Geikie Text Book of Geology, ~~3rd ed., pp. 18-19.~~ 4th ed. pp 24-27 & authorities
cit.

Lord Kelvin, Popular Lectures and Addresses, Vol. II, p. 298.

De Lapparent, Traité de Géologie, pp. 870 et seq.

† "That the climate was becoming differentiated and on the whole cooler than it had been in the earlier Tertiary periods is clearly indicated." 3. Chamberlin and Salisbury, 321.

PREMISE OF SOLAR CLIMATIC CONTROL PRIOR TO PRESENT ERA REJECTED.

It is manifest from these phenomena that the present zonal distribution of temperatures is unique in the earth's geologic history, and that the influences of the cause or causes which controlled the previous non-zonal distribution of climates and of life ceased only within very recent times and that they extended to the inauguration of the existing zonal distribution of climates; and secondly that this latter control has been and is a progressive influence not yet having reached its ultimate stage.

It therefore becomes necessary to reject the assumption* that geologic climates were controlled by that source of heat which developed and maintains the existing zonally distributed climates, namely solar energy; and we must attempt the solution of the problems of geologic and present climates without the use of this assumed premise. The rejection of this assumption involves the acceptance of a new premise to the effect that the non-zonal climates antedating the present era were controlled by a uniformly distributed source of heat, in other words: up to the Ice Age there were two sources of heat: (1) The original planetary heat, however derived, and (2) solar energy, and that the former supply persisted until the culmination of the ice age when by its exhaustion solar energy was left as the sole and existing source.

Fortunately the basis of this new premise is well laid. It is universally admitted that at the dawn of geologic time a sensible residual of *a planetary source of heat was present.*†

The functions of this heat whilst present, its mode and time of extinction, have not been fully considered. It is admitted that it was present in the earliest age and is now insensible. Without inquiring into its mode of action, rate of loss and time of extinction as a sensible factor in surface temperatures, it has been simply omitted in the attempts to solve the problems of climatology, and to supply this omission an unproved assumption has been admitted as a premise. Nor has the significance of the cumulative effect of solar energy, since it became the contr~~act~~olling source, been fully recognized.

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*The rejection of this assumption may be made only provisionally for the purpose of considering the argument herein presented. But considering the contradictory and confusing conclusions to which its acceptance has led this rejection may be made permanent, or at least until the assumption shall have been proven to be true.

†The source of this heat is not fully agreed upon, this is immaterial for the purposes of presenting the present argument. Whether this heat was derived through the nebular hypotheses of La Place, the planetesimal hypotheses of Chamberlin, a combination of these or through some entirely different process and source is not essential.

We will consequently first take up the broad problem of the climatic changes of geologic and present time without the assumption that the former climates were controlled by solar energy alone, and on the basis that at the dawn of geologic time the two sources of heat existed.

It is not necessary to fully reproduce here the specific arguments based on this premise—it is sufficient to give only the synopsis and conclusion as reviewed by Doctor Hilgard of the University of California.

"It is evident that whatever may have been the original source of that heat, * whether from cosmic contraction or planetesimal collision, it has existed and exists now, even though practically insensible at the earth's surface. Even if, as some believe, to-day's vulcanism were only 'skin-deep,' the evidence of former much greater heat is too strong to be set aside. That this heat must have been brought up from the depths of the earth-mass by water, aqueous vapor and other gases, as is now the case in volcanic eruptions, and is also being done by geysers, can not be questioned. Whatever part chemical action, the friction or collisions connected with faults, or that accompanying flexures of strata may have in generating heat, that heat-generation must have been much more active in times of higher original temperatures and active mountain-making. It seems as though, despite all contrary suggestions thus far made, a higher temperature at the earth's surface than exists at present, within the geological ages covered by the warm-temperate flora and fauna found also in the arctic regions, may fairly be presumed on physico-geological grounds alone. This reasonable assumption forms the basis of Manson's theory of the ice age.

"It can not be doubtful that during any highly heated condition of the globe, of whatever origin, the bulk of the water now gathered in seas, lakes and rivers existed in the form of vapor, which as it ascended was condensed into a mass of clouds forming a thick spheroidal envelope all around. On the outside upper surface of this cloud-sphere the sun exerted substantially the same zonal effects as it now does upon the

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* Original, planetary heat.

earth's surface, modified mainly by the uniformity of the physical nature of the cloud-surface, as against the alternation of sea and land as they now exist, and which by their differences in the absorption and radiation of heat, in heat capacity, and in topographic features, modify profoundly the typical, regular zonal order of climates. The tropical belt with its strong ascending currents, low barometer, and high temperatures; the two adjoining arid belts with descending currents and high barometer, and the temperate zones to poleward of the same, with variable but generally low barometer, would be defined on the cloud-spheroid as they are now on the earth's surface, but with greater regularity, though perhaps less sharply. It is also clear that, though not directly influencing the temperature of the earth's surface, the solar radiation would act powerfully as a conservator of earth-heat, compensating to some extent the radiation into space from the cloud-surface, of the heat carried up by convection currents.

"The general disposition of the rain-belts would also be substantially as it is now, but the amounts of rainfall would, in so thick a cloud-cover, undoubtedly be greater than at present. The isothermal spheroids or shells corresponding to our present temperatures would at first be at heights more considerable than at present; but as the heat carried up from the earth's surface was more and more lost by radiation into space from the exterior cloud-surface, the isothermal shells would gradually descend, and the temperature of the falling rains would become lower, so as under favorable conditions to fall as snow. It is clear that snowfall might occur at any period of the earth's evolution on high mountain ranges or plateaus, and there the accumulation of snow might at any period have formed nevées and glaciers with their well-known effects. The earlier glaciations observed, especially in the Permian, are, therefore, quite compatible with Manson's theory. Elevation as a cause of glaciation must, however, be accompanied by its necessary correlative factor, an abundant rainfall; a point frequently left out of consideration in this connection. Labrador is a conspicuous example of non-glaciation from low precipitation.

"Owing to the higher radiating power of the earth-surface as compared with the ocean, as well as to its much lower specific heat, the earth must have cooled more rapidly than the oceans by radiation alone. In addition to this, the water flowing from it into the seas would carry off a large amount of heat. Even while the ocean still received heat from its bed, the land areas would be a cooling agency especially for the ocean depths, while the warm oceanic surface waters would be supplying abundant vapor for precipitation on the relatively colder land areas. The latter would finally fall to so low a temperature as to receive their precipitation in the form of snow, thus inaugurating the glacial period, during which the isothermal shell of say the freezing-point of water, and below, descended near to the earth's surface. As the ocean gradually also cooled and evaporation diminished, the protecting cloud-envelope became thinner, first in the tropics and the flanking belts of lesser rainfall (which later became the arid belts); and thus gradually the zonal solar régime was established.

"Such are main features of Manson's theory, the details of which have been elaborated in his published treatise on the Evolution of Climates and other papers, and the substance of which will be presented to this body by the author himself. In my view it is not a conception to be lightly set aside, for whatever evidences of former glaciations may have been observed, there has not appeared in former geologic history anything resembling in magnitude the pleistocene glaciation, the scattered remnants of which are even now in gradual retreat under our eyes. The observed evidences of glaciation in former geologic ages do not appear to be of such extent, or to be accompanied by detrital deposits indicating a continental extent of glaciation; they are apparently such as might be produced at any time by either the upthrusting of mountain chains, or by wider, epeirogenic elevations of the surface. Thus far, it seems as though there had been but one distinctively glacial epoch of world-wide importance and extent, and that nearly contemporaneous with the appearance of man upon earth."*

Profs. Chamberlin and Salisbury seem to have almost reached the same conclusion: "The deep oceanic circulation is now dominated by the *polar* temperatures, for it is the cold waters of the polar regions that. descending and flowing towards the equator, control the temperature of the deep sea. This is now low because of the low temperature of the polar regions; but if the circulation of the sub-carboniferous and carboniferous periods, whatever its nature, kept the polar regions at a mild temperature, the great body of the deep sea must have had temperatures correspondingly higher, and the water must have had so much the less depressing influence on the temperature when it rose to the surface. This must have contributed to the widespread warmth which the subcarboniferous, and perhaps the carboniferous, period enjoyed. The mildness of climates in these and several other periods, before and since, is one of the most remarkable climatic features of geologic history. The crucial feature is the maintainance of a mild temperature throughout the long polar night. Almost the only approach to a satisfactory solution seems to lie in a warm oceanic circulation blanketed by a heat-retaining atmosphere, in which vapor of water and carbon dioxide;* abetted by a prevalent mantle of clouds generated by the warm ocean, conjoined their equalizing and conservative influences." [2. Chamberlin and Salisbury, 658-9.]

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* *Hilgard, Nature.* Vol. XXV. March, 1907. pp. 351-3.

See also the Author's views in:—

The Cause of the Glacial Period. Trans. Tech. Society of the Pacific Coast, 1891.

Geological and Solar Climates: A Thesis. 1893.

Cosmic Character of the Ice Age. Glacialists' Mag., Vol. II.

The Evolution of Climates. Am. Geol. 1899. Reprint, 1903.

Climats des Temps Géologique. Mexico, 1906.

CONDITIONS OF CLIMATIC CONTROL PRIOR TO THE PRESENT ERA.

By applying the line of reasoning here outlined to the evidences of glacial phenomena at any geologic horizon, except the pleistocene, it will be observed: (1) That under the dual control of climates by residual planetary heat and solar energy glaciation could occur at any latitude and at any period of geologic history, *provided that,* land areas, mountain chains or peaks were thrust up above the snow line of that period:

(2) That the uniformity of the cloud surface and the continuous exposure of the upper atmosphere to solar energy would establish a more uniform distribution of its effects than at present prevails on the variable land and water surfaces now irregularly and intermittently exposed to this energy, and varying widely in elevation and specific heat.

Under the earlier conditions there must have been established in the upper atmosphere, corresponding but more uniformly distributed effects, than we now find: (1) In the three great zones of minimum barometric pressure and of maximum upcast currents, cloudiness and precipitation about the equator and Lat. ±50 degrees; and (2) in the two great intermediate zones of downcast currents about Lat. ±30 degrees, in which maximum barometric pressures and minimum cloudiness and precipitation prevail.

There would thus have been maintained throughout all geologic time a distribution of solar energy effects corresponding to those now found, gradually approaching and finally reaching the planetary surface as earth heat faded. These early conditions would in part determine the distributions of barometric pressure, cloudiness and precipitation. These distributions, by reason of the sphericity of the exposed surface and the sensible parallelism of the rays of energy, must have been arranged in zones.

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* "but it seems clear that the efficiency of the vapor is several times that of the dioxide." 2. Chamberlin and Salisbury, p. 672.

The following conclusions seem to be justified:

(1) The tropical belts, about Lat. ±30°, having for all geologic time been regions of maximum barometric pressure, were, during the eras preceding the Ice Age, regions in which the spheroidal isotherms were most depressed and cold downcast currents most liable to persist. They were therefore especially exposed to early local glaciation; *but,* being also regions of minimum cloudiness and precipitation were earliest exposed to the ameliorating influences of solar energy. (2) That denser and persistent cloud formations would have protected glaciers at and above the snow line as well as warm-temperate and tropical life at or near sea level. (3) That these distributions of glacial ice and life were independent of latitude and dependent solely upon altitude, and possibly also upon the localization of persistent downcast currents of cold air in regions of permanently high barometric pressure. (4) That the interception of solar energy in the upper cloud regions and the trapping of dull heat rays in the lowest regions of the atmosphere would cause the snow line to be lower for a given sea-level temperature than under present conditions, when solar energy by direct and reflected action is an additional and highly effective factor to the dull and quickly absorbed heat rays emitted by the planetary surface, and to convection currents of warm, moist air produced thereby. These agencies were the direct and controlling sources of surface heat during the prevalence of the planetary supply. (5) That upon the exhaustion of this supply evaporation from the finally cooled ocean became insufficient to maintain persistent clouds and that in regions of least cloudiness solar energy first penetrated to the planetary surface: that by continuous exposure and by the cumulative accession of heat derived from this source, through the trapping process, present conditions were gradually developed.

THE PROBLEMS OF CLIMATES SIMPLIFIED.

If therefore we reject the unproved assumption of solar control of non-zonal, geologic climates, and accept the dual source of heat up to the culmination of the Ice Age, (when natural processes distinctly record a change in the mode of heat distribution from non-zonal to zonal,) the phenomena of geological climates and those of the present fall into logical sequence within reasonable explanation through the laws of physics as at present developed. It appears to the writer that this assumption, and overlooking or neglecting the great control which water in its various forms exercises on the modes and rates of loss and reception of heat and radiant energy, and the significance of the difference in temperature distributions before and after the ice age are the reasons why the great problems of past and present climates have remained unsolved.

APPLICATION OF THESE PRINCIPLES TO THE PROBLEM OF PERMIAN GLACIATIONS IN SOUTH AFRICA.

It will be observed that under this interpretation and argument: (1) that ice, as a geologic agent of magnitude, may have been active during any era of geologic time; that the limits and times of its activity may have varied with variations in elevation, or with variations in the available supply of heat derived from the fading planetary supply; (2) that evidences of the gravitative action of ice, in the absence of evidences of life of arctic habit, do not justify the broad conclusions that they represent glacial periods or epochs, and that they are not referable to climatic conditions controlled by solar energy; (3) that until the culmination of the ice age, solar energy was only a conservative factor, gradually establishing its control as the lesser local supply was slowly and finally exhausted from the oceans, and that only upon the exhaustion of this supply was the zonal distribution of climates and of life distinctly inaugurated; (4) that this new control is yet in progressive development.

The explanation which the writer offers for the specific problem in hand—namely, the "puzzle" of Permian glaciation in South Africa,—is therefore simple. It is one of several extensive local glaciations due to elevation,* and independent of latitude, and occurring during a series of gradually fading climates controlled by planetary heat, which heat was conserved by denser cloud formations than now prevail and by the action of solar energy on their outer surface. These and similar glacial formations were protected from direct solar energy by the denser cloud formations due to the universally warmer oceans of pre-pleistocene time, in which, by virtue of the high specific heat of water, was resident the last effective remnant of planetary heat.

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* Geologists generally note that the Permian was a period of marked continental upheavals and of the withdrawal of oceans from previously submerged areas.

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